VOLUME 76 SEPARATE No. 3

Illinois U Library

PROCEEDINGS

AMERICAN SOCIETY OF CIVIL ENGINEERS

FEBRUARY, 1950

AMERICAN SOCIETY OF CIVIL ENGINEERS FOUNDED 1852

TREATMENT OF FOUNDATIONS FOR LARGE DAMS BY GROUTING METHODS

By A. W. Simonds and Fred H. Lippold, Members, ASCE, and R. E. Keim, Assoc. M. ASCE

POWER DIVISION

Headquarters of the Society
33 W. 39th St.
New York 18, N.Y.

PRICE $0.50 PER COPY

The Society is not responsible for any statement made or opinion expressed in its publications

---

Published at Prince and Lemon Streets, Lancaster, Pa., by the American Society of Civil Engineers. Editorial and General Offices at 33 West Thirty-ninth Street, New York 18, N. Y. Reprints from this publication may be made on condition that the full title of paper, name of author, page reference, and date of publication by the Society are given.

Copyright 1950 by the AMERICAN SOCIETY OF CIVIL ENGINEERS
Printed in the United States of America

AMERICAN SOCIETY OF CIVIL ENGINEERS
Founded November 5, 1852
PAPERS

TREATMENT OF FOUNDATIONS FOR LARGE DAMS BY GROUTING METHODS

By A. W. Simonds [1] and Fred H. Lippold,[2] Members, ASCE, and R. E. Keim,[3] Assoc. M. ASCE

Synopsis

Present-day methods used in grouting foundations of large dams were developed for the purpose of reducing seepage under and around the structures and for improving the load-carrying properties of the foundation rock. These methods received impetus in the early 1930's during the construction of Hoover Dam in Arizona and Nevada. Since that time the foundation designs for nearly all large dams constructed in the United States have included extensive grouting programs. Although foundation grouting is still in the process of development, a more or less rudimentary report of the present equipment, materials, and procedures used in foundation treatment seems pertinent.

The information contained in this paper, for the most part, is based on experiences gained in grouting the foundations of twenty or more large dams. This information is presented under three main headings—foundation grouting equipment, grouting materials, and foundation grouting procedures. In the main, the paper is concerned with the application of neat-cement grout. The use of other foundation grouting materials, such as asphalt, bentonite, and clay, is also discussed. One important method of foundation treatment, chemical grouting, is not discussed in this paper since it is not as yet generally used by the Bureau of Reclamation (USBR), United States Department of the Interior.

Introduction

The proper foundation treatment of large dams is one of the major problems of modern construction. In order that the superimposed structure may

Note.—Written comments are invited for publication; the last discussion should be submitted by July 1, 1950.

[1] Engr., Bureau of Reclamation, U. S. Dept. of the Interior, Denver, Colo.

[2] Engr., Bureau of Reclamation, U. S. Dept. of the Interior, Denver, Colo.

[3] Engr., J. Gordon Turnbull, Inc., Richland, Wash.; formerly Engr., Bureau of Reclamation, Denver, Colo., and TVA, Knoxville, Tenn.

function as designed, it is essential that the foundation support the maximum loads applied to it. If the foundation rock in its natural state is inadequate, it may be possible to remedy the existing defects and improve the rock so that it will provide suitable support. The injection of grout into defective foundations is a practical method of improvement.

Pressure grouting is the process by which mixtures of cement, water, or other materials are forced into confined and inaccessible spaces for the purpose of consolidating the mass as a whole. Pressure grouting is being used by the USBR primarily for the elimination of seepage and the reduction of uplift pressure in the foundation beneath the structure. It also increases the bearing strength of the foundation rock by filling any voids or fissures that may be present.

The reduction of seepage and uplift pressures beneath a masonry dam is generally effected by grouting the foundation through deep holes spaced at close intervals in one or more rows parallel to the axis of the structure. This procedure (known as "curtain grouting") is supplemented by a row of drainage holes drilled a short distance downstream and parallel to the grout curtain. The function of these drainage holes is to relieve any hydrostatic pressure that may develop from seepage water passing through the grouted zone.

Before a foundation grouting design can be prepared for a dam site, the foundation should be explored thoroughly. Data obtained from the exploration of the foundation are used to determine the following:

1. The type and the size of dam suitable for the site;
2. The properties of the foundation rock;
3. The location of faults, fractures, seams, and cavities; and
4. The suitable grouting plans.

Grouting Plans

In the construction of large dams, the USBR uses three classes of grouting—known as low-pressure, intermediate-pressure, and high-pressure grouting. They may be used collectively or singly as required for a particular foundation. A typical arrangement of grouting pressure zones is shown in Fig. 1. In a normal construction program, low-pressure grouting is done first. This consists of blanket grouting to seal and consolidate the part of the foundation near the surface. Intermediate-pressure grouting is used to effect a deeper seal in the foundation along the upstream edge of the structure. High-pressure grouting is used to form the main cutoff curtain to reduce seepage beneath the structure. In addition, special grouting may be required to seal spring drains, to consolidate the rock around tunnels, and to stop occasional leaks within the foundation rock.

In the construction of concrete dams, low-pressure blanket grouting is performed in the surface rock in the upstream third of the foundation area. If necessary, this type of grouting may be used in the entire foundation area. Blanket grouting for earth dams, if needed, is usually confined to the near-surface part of the foundation rock adjacent to the cutoff walls. It is utilized under any type of dam to seal the near-surface bedrock where zones of weakness occur.

Low-pressure grout holes are usually drilled to depths varying from 10 ft to 50 ft. The axis of the hole is taken normal to the foundation surface except where it is parallel to a seam; when this condition occurs, the hole is drilled at an angle with the foundation surface so that the hole intersects the seam. The pressures used depend on the size and type of the structure and on the foundation conditions. In general, pressures are maintained as high as possible without producing detrimental uplift of the foundation rock. The range of pressures used varies between 20 lb per sq in. and 150 lb per sq in.

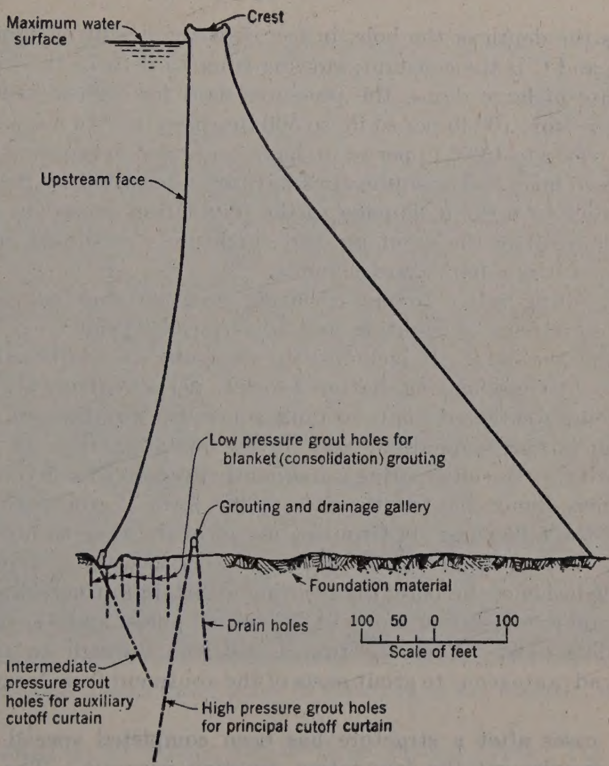

Fig. 1.—Zones of Pressure Grouting Beneath a Large Dam

Intermediate-pressure grout holes in concrete dams may be drilled from the surface of the foundation rock just upstream from the edge of the structure, or through pipes placed in the upstream fillet at the base of the dam. The depths generally range from 50 ft to 100 ft depending on conditions encountered. The pressures used depend on the weight of the concrete on the foundation at the time of grouting, and also on the geologic structure and strength of the foundation rock. Normally, these pressures range from 75 lb per sq in. to 400 lb per sq in.

High-pressure grouting to form cutoff curtains is used in the construction of both concrete and earth dams. In constructing large concrete dams, this

grouting is generally done from a gallery adjacent to or slightly downstream from the axis and close to the foundation rock. Pipes extending from bedrock to the gallery are placed in the concrete during construction. The holes are drilled and grouted with high pressure through the pipes after concrete has been placed to a reasonable height above the foundation. The depths of these holes vary since they depend on geologic and topographic conditions. For some dams the following criterion has been used for determining the depth of holes in the cutoff curtains:

$$d = \tfrac{1}{3}h + C \qquad (1)$$

in which d is the depth of the hole, in feet; h is the height of dam above the hole, in feet; and C is the constant, varying from 25 ft to 75 ft.

In the case of large dams, the pressures used for high-pressure grouting normally range from 100 lb per sq in. to 500 lb per sq in. In a few exceptional cases, pressures up to 1,000 lb per sq in. have been used in grouting the bottom sections of deep holes. These pressures have been localized by packers in the holes. In order to prevent damage to the foundation caused by heaving or uplifting as a result of the grout pressure, high pressure should be used with caution and never in a haphazard manner.

Special grouting refers to any grouting program that supplements the aforementioned classes of grouting and is performed prior to or during the construction of the dam. It includes: (*a*) Grouting an additional curtain to reduce uplift; (*b*) consolidating shattered rock to permit cutting of steep slopes; (*c*) consolidating weathered joints or fault zones; (*d*) grouting off springs and other leakage in the foundation; and (*e*) consolidating rock to increase its bearing capacity. Special grouting is frequently necessary for diversion tunnels or other tunnels appurtenant to the dam. This form of grouting may include any or all of the following: (1) Grouting ahead of the bore to prevent caving or to shut off flows of water; (2) filling the void between the arch of the tunnel lining and the inside of the bore; (3) grouting a curtain in the rock surrounding the tunnel intake; (4) sealing joints in the tunnel plugs; and (5) consolidating the surrounding rock. When the tunnel is driven through an abutment, it is sometimes advantageous to grout parts of the abutment from locations within the bore.

In some cases after a structure has been completed special grouting is required to supplement the foundation grouting program. The purpose of this grouting is to reduce uplift pressures and to cut off excessive seepage. To accomplish this it is occasionally necessary to grout fractures that have been opened by saturation of unstable materials or by deformation of the foundation by superimposed loads.

Foundation Grouting Equipment

Equipment used in pressure grouting operations has undergone considerable development in recent years. Essentially, it consists of grout pumps, grout mixers, water meters, agitator sumps, pressure gages, packers, pipe lines and fittings, and miscellaneous supplies. Fig. 2 shows the grout plant used by the contractor at Davis Dam on the Colorado River in Arizona and Nevada.

For injecting grout a duplex type, positive displacement, reciprocating pump, patterned after the slush pumps developed for use in oil well drilling, has proved satisfactory. These pumps are driven either by compressed air or steam engines or by electric or gasoline motors. A pump properly equipped for cement-grouting service should have special hardened steel liners, rubber pistons, combination steel and rubber valves, and hardened steel valve seats. With a properly designed and equipped grout pump, it is possible to control the pressures closely, to provide a variable rate of injection, and to minimize clogging of valves and feed lines.

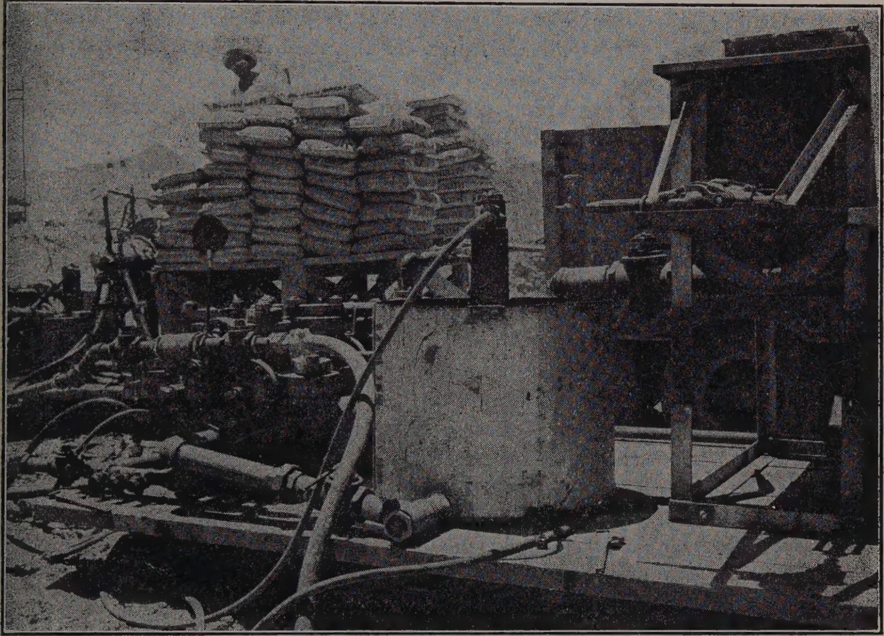

FIG. 2.—CONTRACTOR'S GROUT PLANT AT DAVIS DAM ON THE COLORADO RIVER

Reciprocating grout pumps are of three general types: The line type, the side pot type, and the divided fluid end type. These pumps can be obtained in sizes varying from $5\frac{1}{4}$ in. by $3\frac{1}{2}$ in. by 5 in. to 10 in. by $7\frac{1}{4}$ in. by 10 in. Sizes commonly used are 6 in. by 4 in. by 6 in., 7 in. by 3 in. by 10 in., and 10 in. by $4\frac{1}{2}$ in. by 10 in. In the line type (shown in Fig. 3) the discharge valves are located directly over the suction valves so that both can be removed through the same opening in the top. The advantage of this type lies in the accessibility of the valves, as only one cover plate needs to be removed to reach two valves in the event that the valves require cleaning. In the side pot type of grout pump each valve is located in a separate pot or chamber. Each valve pot has an independent cover which must be removed before the valve can be reached. The advantage of this type of pump is that all valves and seats are interchangeable. Furthermore, each valve has a separate cover

plate which permits the suction valves to be removed and cleaned without disturbing the discharge valves as in the case of a line type of pump. The divided fluid end type of pump is a special variety of the side pot pump which has separate removable cylinders. Each of the foregoing types is designed to pump grout at any required pressures to a maximum of 1,000 lb per sq in. Their capacities range from 20 gal per min to 100 gal per min.

Since cement grout is highly abrasive, component parts of a grout pump are designed to resist abrasion. These component parts include the valves, liners, pistons, piston rods, packing, and oilers. Fig. 3 shows the locations of these parts in a pump properly fitted for cement-grouting service. The valves are of special design and are drop-forged from alloy steel and have steel bumpers and rubber inserts. The seal is formed by the rubber insert and the metal valve seat. Balata and fiber inserts are not satisfactory.

The cylinder liners are removable sleeves that fit into the main body of the pump. They may be fabricated from separate shells, the outer one machined from cast iron or steel and the inner one from casehardened steel, or from a single shell of casehardened steel. In either type, the inner surface should be honed to a mirror-like finish. Liners in new pumps should be removed and inspected for defects before using the pump. When inserting the liner, a copper-bound asbestos gasket or a gasket cut from sheet cork should be fitted between the shoulders of the liner and the cylinder block. Some pumps are factory equipped with soft rubber sleeves between the liner and the block. Sleeves of this type have not proved effective in preventing grout from passing between the liner and the block. A satisfactory seal can be obtained by installing several courses of hydraulic packing painted with either white lead or a mixture of grease and graphite. The outer surface of the liner should be coated with waterproof grease to prevent it from seizing to the block and to facilitate its removal during disassembly of the pump.

Pistons for cement-grouting service are made of a medium-soft rubber molded onto a steel core so the unit may be fastened to the end of the piston rod. They are nearly cylindrical in shape with each end slightly flared or enlarged. The flare sweeps the inner surface of the liner clean with each stroke, thereby preventing grout from collecting between the piston and the cylinder.

Pump rods are important parts of grout pumps. Untreated steel rods are a continued source of trouble whereas rods that are properly casehardened and ground, and have a polished surface, give excellent service. For air-driven or steam-driven pumps, it is desirable to use piston rods made in two sections. The air end section transmits the force to the pump from the piston in the engine, and is subject to little wear. The liquid end section drives the piston in the pump and is subject to considerable wear where it passes through the packing gland. Piston rods for the liquid end section should be made of casehardened or stainless steel.

Proper packing around the pump rods is necessary for efficient operation. For the air end, a good grade of steam packing should be used. For the liquid end, braided graphite packing has been used for low-pressure grouting. For intermediate-pressure and high-pressure grouting, a chevron type packing will

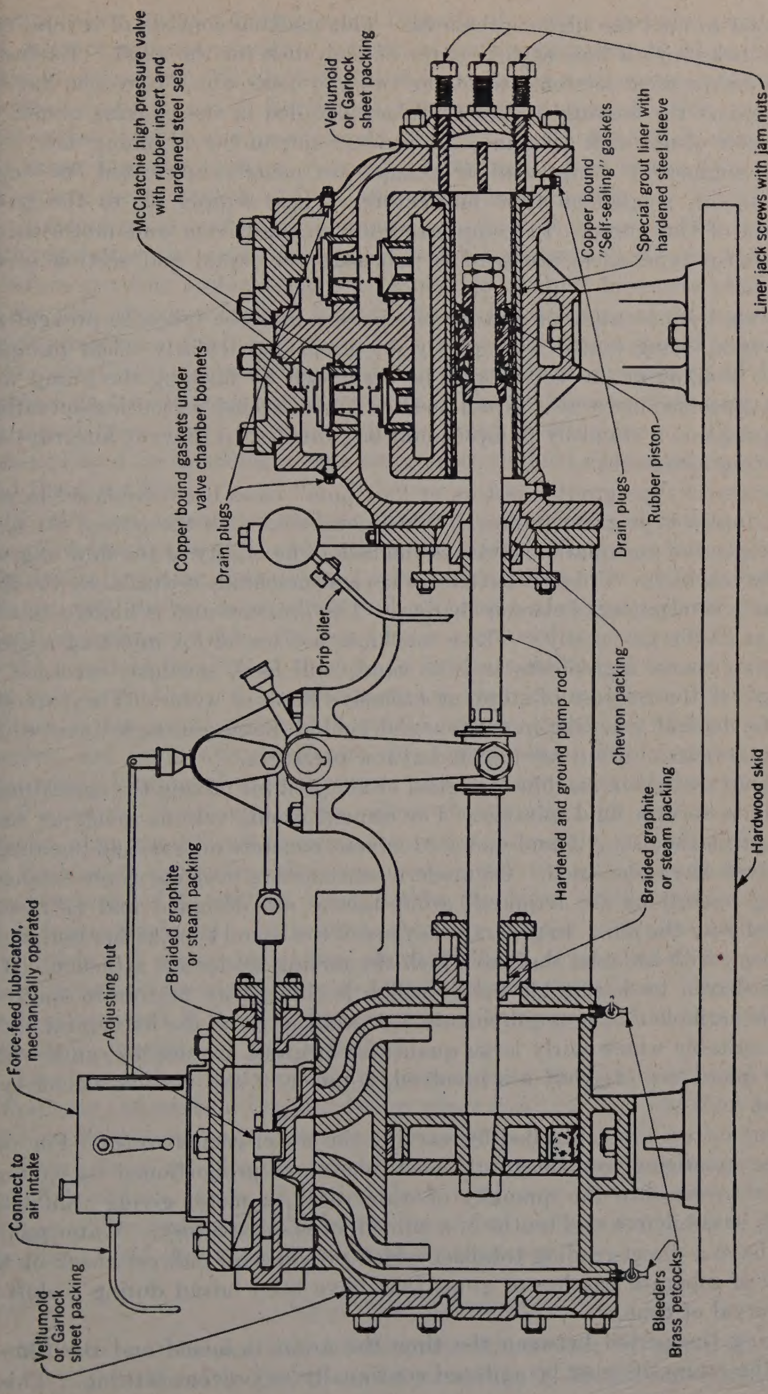

Fig. 3.—Line Type of Slush Pump Equipped for Cement-Grout Service

be needed to hold the higher pressures. This packing consists of several cup-shaped disks with a hole at the center of each disk for the shaft. Each disk has a V-shape cross section, except the two end disks which have one flat side to fit against the bearing surfaces. When installed in the packing gland, the convex side of one disk nests into the concave side of the adjoining disk.

The engines of compressed-air pumps are usually lubricated by single-compartment, single-feed type lubricators. These supply oil to the power cylinders of the pump. In compressed-air, steam-driven, and motor-driven pumps, drip type oilers are used to lubricate the liquid end section of the pump rod.

During the operation of a grout pump, care must be taken to prevent the valves from being fouled with partly-set grout, particularly when pumping slowly. Fouling of the valves may be prevented by flushing the pump with water at specified intervals. For dam sites where extensive grouting operations are in progress, a stand-by pump should be provided to prevent interruptions in grouting operations.

Pneumatic type grout injectors or "air pots" have been displaced largely by the duplex type grout pumps. When compared with the pump, the chief objection to the pneumatic injector is the lack of flexibility of the flow of grout from the machine. Unless a battery of several machines is available, the flow of grout is intermittent between charges. The pressure also is limited to that of the available air supply. These machines are useful for injecting a grout containing coarse ingredients such as sand, mill feed, sawdust, excelsior, or shavings for the purpose of stopping excessive flows of water. They are also useful for backfill grouting in tunnels and behind metal penstock liners where small quantities of grout are injected at low pressures.

A grout mixer is a machine designed or adapted for mixing the constituents of grout to form a fluid mixture. For cement grout, various machines have been used in the past. Hand-operated mixers, concrete mixers, and pneumatic type mixers have been used. On modern construction projects where extensive grouting operations are required, grout mixers are designed and fabricated specifically for the job. In general, they are of the barrel type, either horizontal or vertical, with an axial shaft to which the mixing blades are attached. The shaft is driven by a suitable motor which is sufficiently flexible in speed to meet the variable mixing requirements. A grout mixer of the horizontal barrel type is suitable where fairly large quantities of grout are needed; and, where smaller quantities of grout are involved, a mixer of the vertical barrel type is useful.

Grout mixers are controlled by varying the water-cement ratio. For convenience in mixing, cement-grout constituents are proportioned by volume. In order to measure the quantity of water used, a meter giving volumetric readings in cubic feet and tenths of a cubic foot is satisfactory. Water meters should have a direct-reading totalizer which provides an indirect check on the number of separate batches of grout that have been mixed during a shift or any interval of time.

During the period between the time the grout is mixed and the time it enters the pump, it must be agitated continually to prevent settling. This is

accomplished by an agitator sump between the mixer and the grout pump. An agitator sump is usually a cylindrical tank approximately 30 in. high and 36 in. in diameter. Within the tank is an agitating mechanism consisting of a vertical shaft to which horizontal blades are connected. The agitator is operated at a speed of approximately 30 rpm. As the grout is discharged from the mixer into the agitator, it is passed through a wire screen (No. 4 mesh) to remove pieces of sack, strings, and other foreign matter.

Pressure gages graduated in pounds per square inch are used for controlling and regulating the grout pressure. Reliable pressure gages are essential in pressure grouting systems, since a knowledge of grout pressures at the collar of the hole affords a method of determining the behavior of the hole and the uplift pressures in the foundation rock. At least two gages should be connected in the grout system, one at the pump to register pumping pressure and the other at the hole to indicate grouting pressure. The mechanism of the gage must be protected from direct contact with the grout in the system. This may be accomplished by installing a gage saver or an oil filled siphon between the gage and the grout line.

Grout line accessories include pipe, fittings, hose, and valves. Usually, standard black iron pipe and fittings are suitable for grout lines. For most foundation grouting operations, 1.5-in. pipe is used. Grout hose must be a pliable, soft rubber hose which will withstand abrasion and the maximum grouting pressures used. Rubber hose is often used to connect the supply line to the manifold (header) at the hole to facilitate shifting of the grout line from one hole to another. Stopcock valves are used on grout lines. In the piping system at the grout pump, the control valves, which are subject to heavy service, are frequently lubricated plug stopcocks. This type of valve is thoroughly lubricated under pressure and is easily operated since it does not bind or stick. Gate and globe valves should never be used in grout lines because they are difficult to clean, they wear out rapidly, and they plug easily.

Packers or expanding plugs are devices inserted into holes to localize the pressure applied to certain zones within the hole. Many types of packers have been developed. In general, they are classed as removable and nonremovable. A removable packer, shown in Fig. 4, is installed in the grout hole for washing and grouting the part of the hole below the packer. Nonremovable packers are used if there is danger of their being grouted to the wall of the hole, or if a permanent plug is desired.

Dye is used to find the paths and, occasionally, the source of water through cofferdams and parts of the foundation where leaks occur. The dyes generally used are fluorescein or potassium permanganate.

Grout leaks are plugged by the use of many different calking materials, including oakum, strips of burlap, lead wool, and various sizes of wooden wedges. The wedges should be cut from dry, well-seasoned white pine, or any other wood that expands appreciably when wet.

Grouting Materials

Material suitable for consolidating foundation rock by grouting methods must: (1) Be sufficiently fluid to permit pumping; (2) be sufficiently fine grained

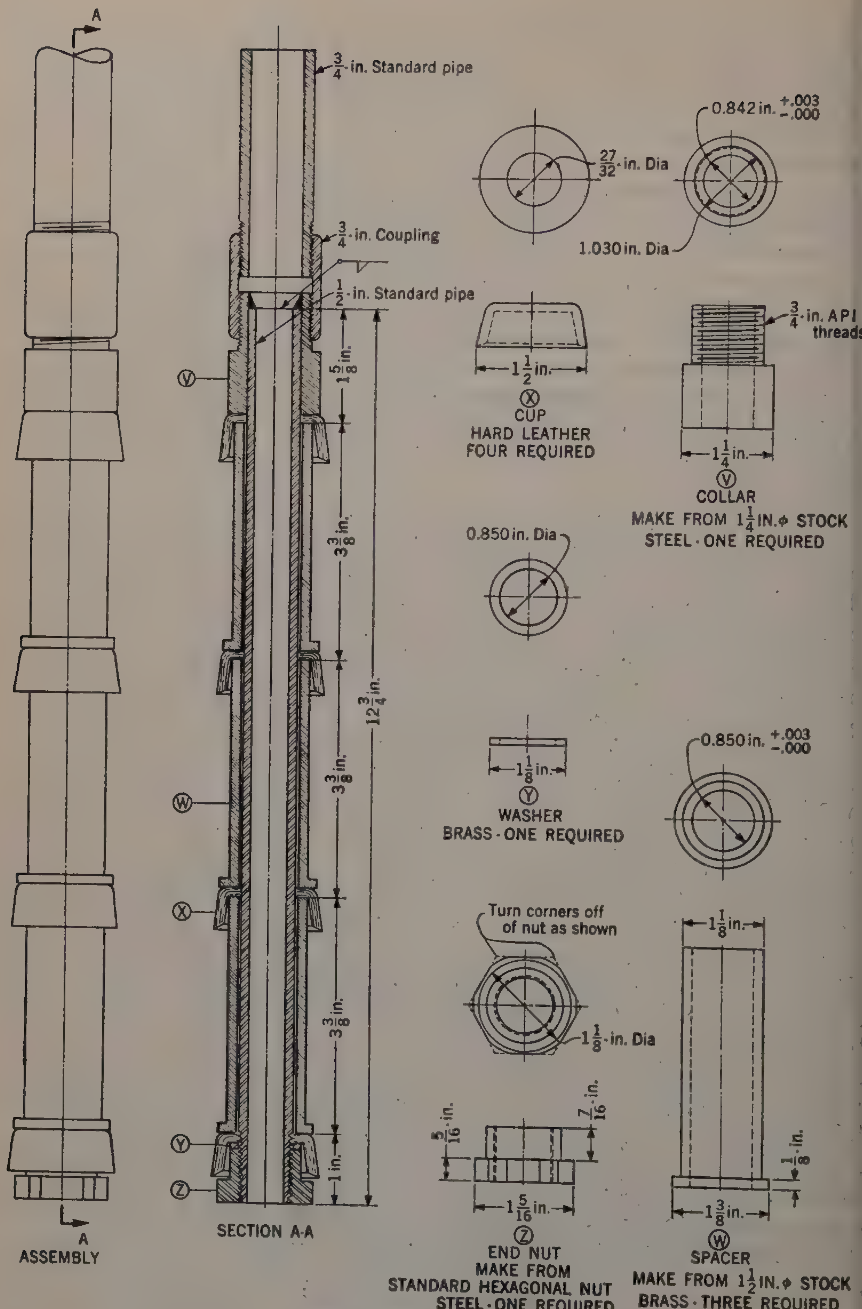

FIG. 4.—REMOVABLE PACKER FOR GROUT HOLES

to pass, under pressure, into very small openings and cracks; (3) form a substance with adequate bearing strength when set; and (4) set with a minimum amount of shrinkage. When placed under pressure, a mixture of Portland cement and water normally satisfies these conditions. For grouting cofferdams, small dikes, and reservoir rims, and for sealing off large flows of water, many materials may be used either separately or in combination with cement. Some of these are clay, bentonite, chemical compounds, asphalt, sawdust, cinders, hay, straw, oats, and silicas. Once placed, these are usually backed up by cement grout.

Cement-Grout Mixtures

The most widely used form of grout is a mixture of standard or modified Portland cement and water. For convenience, these substances are proportioned by volume. The water-cement ratio used depends on the tightness of the foundation rock. If the rock contains large voids which accept grout readily, the water-cement ratio may be 1:1. For tight seams or cracks in the rock, ratios of 20:1 have been used. The usual grout mixes are proportioned within the limits of 1:1 and 10:1. Thin grout placed under sufficient pressure to force out the excess water will form a hard, durable film. Neat-cement grout is easily pumped; it adheres to clean rock surfaces; and, when properly placed, it has relatively high compressive strength. It is used to consolidate foundation rock, to form a cutoff curtain under dams, and to grout contraction joints contained within large mass-concrete structures.

Clay or a mixture of clay and cement may be used as grout when a sealing filler is required in parts of the foundation that do not require strengthening. For example, it may be used to grout cavities and to form blankets or sealing mats within porous rock and alluvium. Clay used as grout must form a mixture suitable for pumping when combined with water, have minimum adhesiveness, and be free from organic or foreign matter. Before mixing, the clay should be screened through 1.5-in. hardware cloth to remove lumps, rocks, or other material that might damage the pump, or plug the grout lines. For clay-cement grout, minimum shrinkage is obtained when the mixture contains three parts of clay to one part of cement by volume. To this mixture, sufficient water is added to make the grout suitable for pumping. The equipment and methods used for placing clay grout are the same as those used for cement grout.

Bentonite is a soft, moisture-absorbing, colloidal clay found in various localities throughout the western United States. It has the following properties which, under special conditions, make it useful as grout: (1) It will absorb three or more times its own weight of water and, in so doing, will increase in volume seven or more times its dry bulk volume; (2) it is easily pumped when mixed with water; and (3) it is fine grained. Bentonite may be mixed with sand or cement to grout off large flows of water, which cannot be grouted effectively with cement grout.

Chemical Grout

Chemicals are used for grouting by mixing, either prior to pumping or within the void, two or more solutions of mineral salts. These combine chemically to form another compound which crystallizes into a solid mass

A number of different chemicals have been used for this purpose; but the most common are solutions of sodium silicate in combination with calcium chloride, sodium bicarbonate, or aluminum sulfate. Since these chemicals form a colloidal solution, it will penetrate tighter seams than cement grout. Two methods of chemical grouting are used—the single injection method in which the chemicals are mixed before being pumped, and the double injection method in which the individual chemicals are pumped separately into the foundation.

Asphalt Grout

Hot asphalt has been used to grout cavities or joints which could not be grouted by cement or cement-clay mixes because of the presence of percolating water. Asphalt grouting is expensive, and for that reason it should be used only to grout rock that cannot be sealed by other methods. The equipment required and the methods used for placing asphalt grout are described subsequently.

Special Grouting Mixtures

A mixture of Portland cement, fine well-rounded sand, and water has been used as a grout mixture to economize on cement. Grout mixtures containing a highly abrasive material, such as sand, usually are not satisfactory for grouting foundations because: (1) The sand grains are too large to penetrate into the small voids; (2) the mixture causes premature plugging within the grout hole; (3) the sand may settle out of the mixture and thereby plug supply lines; and (4) the mixture causes excessive wear of the pump and of the valves in the supply headers. However, sand-cement grout has been used successfully in tunnel-arch grouting, and also for filling large voids in the foundations.

An admixture is a material added to cement grout to control, to a limited degree, the physical properties of the mix. By supplying admixtures to the grout the following properties of the mix may be controlled: (*a*) Workability, (*b*) shrinkage, (*c*) high early strength, and (*d*) setting time. Materials used as admixtures, and the purposes for which they are used, are as follows:

Admixtures	Purpose
Pumicite, or diatomaceous earth	Improves workability of grout mixture
Calcium chloride, very high alumina cement (not Portland), or gypsum plaster	Decreases setting time
Clay, sand, or rock flour	Produces economical mix when filling large voids

Some of the materials are used to set nipples in nearly all grouting operations. They are high alumina cement, plasters, and calcium chloride. Very high alumina cement is used to make a quick-setting mortar for grout nipples. A satisfactory mortar may be obtained by blending 35% of very high alumina cement with 65% of Portland cement. If this blend is proportioned with water in a 0.5:1 water-cement ratio, the resulting mix will have a flash set. Gaging, molding, and other plasters with a gypsum base are used with cement for grouting nipples and patching leaks. A 1:1 mixture of plaster and cement, when mixed with water, will produce a grout that has a flash set. The setting

time can be increased by reducing the proportion of plaster in the mixture. Calcium chloride, when added to neat-cement grout, can be used also to grout nipples and to patch leaks. The mixture should not contain more than 5% of calcium chloride by dry weight. On some jobs, calcium chloride has been added to the grout mix as an accelerator to plug leaks that occur at long distances from the hole. Accelerators should be used only under the supervision of experienced personnel; otherwise, some difficulties may occur due to a flash set of the mixture.

Foundation Grouting Procedures

Basic grouting procedures apply for all foundations requiring treatment by grouting methods. The manner in which these procedures are adapted depends on the judgment of the engineer in charge of the foundation treatment program. When making decisions, he must rely on his experience and on precedent established by the successful treatment of foundations at other dams. From time to time throughout the grouting program, the engineer must be able to decide pumping pressures, consistency of grout mix, location and spacing of grout holes, depth of hole to be grouted in one stage, rate of grout injection, and probable location of grout leaks. In making these decisions, he is aided by information gained from preliminary exploration data, water tests, and "grout-take" of the first series of holes.

The procedure followed in grouting foundations for concrete and earth dams is similar, the main difference being the location of the lines of holes. In the construction of earth dams, the plans for blanket grouting normally provide for lines of holes to be located between the cutoff walls, on either side of a cutoff wall, if only one wall is to be constructed, or over the entire area of the foundation beneath the impervious zone of the dam. The curtain grouting consists of one or more lines of fairly deep holes along or close to the axis of the cutoff wall footing.

In the construction of concrete dams, there are two major grouting operations—blanket grouting and curtain grouting. The blanket grouting plan usually provides for holes to be drilled on 10-ft to 20-ft centers along three or more lines parallel to the axis in the upstream part of the foundation area. The lines are about the same distance apart as the minimum distance between holes. For the curtain grouting, grout holes are normally spaced on 5-ft to 10-ft centers along one or more lines parallel to, and a short distance downstream from, the axis of the dam.

There are no fixed rules for establishing the minimum distance between grout holes. For the most part, this spacing depends on the type and extent of consolidation required in the foundation rock. Some bedrock contains bedding planes and fractures filled with weathered material, which should be removed by washing methods if practicable; that is, grout holes should be drilled close enough so that compressed air and water can circulate between the holes in order to remove the material effectively.

Several empirical formulas have been proposed for determining the depths for drilling grout holes. Although such formulas are satisfactory for rock which is sound and not affected by deep weathering, they cannot be applied

dogmatically for estimating depths to which all grout holes must be drilled. When determining the depth for drilling grout holes, the engineer must have information on the purpose of the hole, the character of the foundation rock, the height and type of structure, and the position of the hole in the grout plan.

The grout supply line is connected to a grout hole through a manifold and nipple. The grout nipple is usually 1.5-in. black iron pipe, with one end threaded and the other end flared for calking, or both ends are threaded and a coupling is screwed on the lower end. The length of the nipple depends on the type of rock to be grouted and on the pressure to be used. In very poor rock, the nipple is extended as much as 5 ft into the hole to prevent excess grout leakage through rock fractures. If the surface rock is sound, a shorter nipple can be used. Usually, grout nipples are bonded to the wall of the hole with a thick grout made from cement with high early strength. They may also be anchored by being calked in place with lead wool.

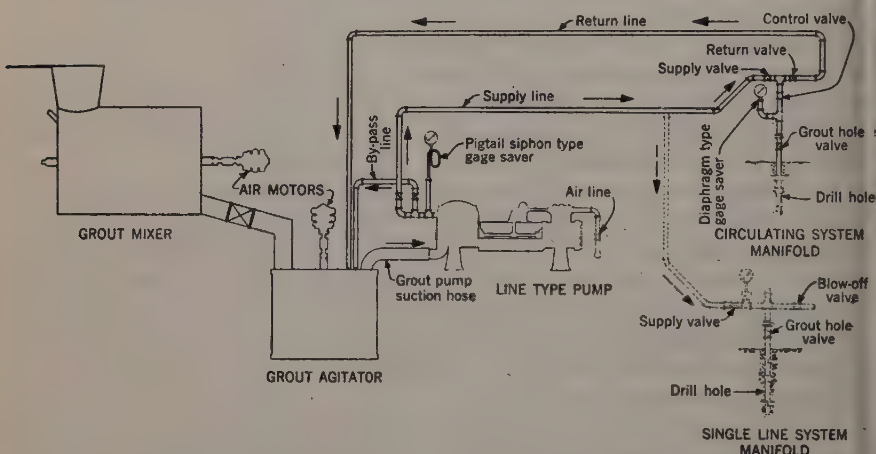

Fig. 5.—Schematic Diagram of Circulating and Single-Line Grouting Systems

The USBR uses two principal systems of piping for supplying grout from the pump to the grout holes. These systems, shown in Fig. 5, are designated as the single-line system (shown dotted) and the circulating system. In the single-line system one line extends from the pump to the grout hole. The connecting manifold has two valves, a supply valve and a blowoff valve. The supply valve is used to hold grout in the supply line when moving the manifold from one hole to another. The blowoff valve is used for clearing or washing the supply line. Beneath the manifold and attached to the pipe nipple is the grout hole valve. This valve is used to retain the grout within the hole when disconnecting the manifold at the union or to prevent water from entering the hole when washing the supply line.

The procedure for grouting with a single-line system is as follows: At the beginning of the grouting operation, when grout is first introduced into the supply line, the grout hole valve is closed and the supply and blowoff valves are opened. As soon as grout of the proper consistency is ejected from the

outlet end of the blowoff valve, the grout hole valve is opened and the blowoff valve closed. When grout is being pumped into the hole, the pressure gage on the manifold must be observed continually to insure that the desired grout pressures are being used. The desired pressure is obtained by varying the speed of the pump, or in an emergency by opening the blowoff valve. When the pressure differential between the hole and the pump becomes excessive, it is an indication that the supply line is becoming partly plugged. This condition can be remedied by closing the valve to the grout hole and opening the blowoff valve. Grout can then be pumped through the supply line at increased velocity to scour out any deposits within it; or the supply line can be flushed with water. The blowoff valve should never be opened or closed in a manner that produces a water hammer in the supply line, with the grout valve open. Such a procedure might plug the fractures in the foundation rock that are penetrated by the grout hole. When the grouting is completed, the grout hole valve is closed to retain the grout within the hole until the grout has set.

The circulating system differs from the single-line system in that a continuous supply line is provided from the pump to the manifold and thence back to the agitator sump. The grout manifold for this system has three control valves in addition to the grout hole valve on the nipple. When starting grouting operations, the grout hole valve is closed and the three control valves are opened. This permits grout to circulate through the line and return to the agitator sump. As soon as grout flows from the outlet of the return line into the sump, the grout hole valve is opened. The desired grouting pressure is obtained by adjusting the return-line valve, or in some instances, by regulating the speed of the pump. It is often advantageous, when grouting large voids, to close the return valve in order to direct the full grout flow into the hole. When this is done the return valve must be opened periodically to replace the residual grout in the return lines with fresh grout. On the completion of the hole, the grout hole and main control valves are closed. With these valves closed the manifold can be disconnected and moved to the next hole to be grouted while the grout is still in the circulating system, unless it is necessary to add additional lengths of pipe to the system.

A brief comparison of the advantages of the two systems follows. The advantages of a single-line system are: (1) It is more economical to install since only one grout line is required; (2) less cement is wasted by cleaning the supply line when operations are temporarily discontinued; and (3) fewer valves and other replacement parts are required. A circulating system is advantageous because: (1) Less tendency exists for the grout lines to become plugged due to settling of cement out of the mix; (2) less cement is wasted when moving the supply line from one hole to another; (3) close control of grouting pressures is possible at the hole; (4) waste grout need not be deposited on the surface of the foundation in the vicinity of the grout holes; and (5) the grout pump remains cleaner because of rapid circulation of grout within the pump chambers.

Several modifications of the single-line and circulating systems are used. One modification is to install a return line to the agitator sump from a point on the supply line close to the pump. This line is equipped with a valve

which is opened during periods when the pump is cleaned. Another modification includes the installation of a blowoff valve on a manifold connected to a circulating system. By this arrangement, the crew can begin grouting the hole as soon as the grout reaches the manifold instead of waiting until it returns to the agitator sump. Furthermore, by regulating the return valve, the system can be converted to a circulating system when the rate of injection decreases or grout leaks occur.

When foundation rock contains open fractures, the pervious and loose material in the fractures should be washed out (when possible) and brought to the surface. Water pumped into the hole, followed by air under pressure, causes a boiling action that breaks up the weathered material, penetrates fractures which connect with other holes, and carries loose material to the surface through adjacent holes. Separate supply lines are connected to a two-way manifold so that air and water can be applied alternately until clear water comes to the surface. The pressure used in washing fractures and seams should be slightly less than the maximum pressure used in grouting.

Grout holes are usually pressure tested with water to determine the consistency of the grout mix to be used, or to locate seams or other openings in the rock through which grout can leak to the surface. To pressure test a grout hole, water is forced through the supply line by the grout pump. When practicable, the pressure maintained should be the maximum that will be used when grouting the hole. The hole is subjected to this pressure for at least 10 min. If the leaks are sufficiently large so that the desired pressure cannot be attained, they must be calked.

Grouting Methods

Four general methods used in foundation grouting procedure are single-stage grouting, grouting by packers, successive-stage grouting, and multiple grouting. The choice of methods suitable for foundation treatment for any one site depends on the type and character of the foundation rock.

The single-stage grouting method consists of drilling the grout hole to full depth, installing the nipple, washing the hole, and grouting the hole in one operation. This method should be used only in grouting shallow holes in sound rock containing only small cracks and joints. Since relatively high pressures are required to attain the proper amount of grout penetration for single-stage grouting, this method should not be used where surface leaks develop in the foundation rock.

The use of packers affords a method of grouting the foundation rock at any required depth. The hole is drilled to full depth, and a packer is set at any desired depth within the hole. The hole can be washed either before or after the packer is placed. When it is necessary to confine washing operations to a limited part of the foundation traversed by the grout hole, washing may be performed after the packer is placed. If the foundation rock contains seams, these may be washed and grouted more effectively by placing a packer at the elevation where the hole intersects the upper limits of the seam. Although the packer-grouting method may be more costly than the single-stage grouting

method in some cases, many foundations may be grouted more effectively when the former is used.

In successive-stage grouting the first stage requires: (1) Drilling grout holes to a predetermined depth; (2) washing this stage of the hole prior to grouting, then water testing the hole and grouting it; and (3) washing the grout out of the hole as soon as the cement has received a partial set. For the next stage the procedure is repeated after the grout in the surrounding rock has fully set. For each stage, as the hole is extended to its final depth, the grout pressures are usually increased.

When compared to single-stage grouting, successive-stage grouting has two principal advantages: (*a*) Increasing grout pressures can be used for increasing depths of hole; and (*b*) the amount of grout wasted at surface leaks is reduced. Successive-stage grouting is a more expensive method of foundation treatment than single-stage grouting.

Occasionally, when attempting to seal off leaks, a thick grout is used during the first stage; and the hole is washed or redrilled as soon as the grout in the rock has attained a partial set. The hole is then regrouted with a thinner mix. This operation is sometimes called multiple grouting.

When grouting a foundation, the grout inspector must decide the water-cement ratio of the initial grout mix and a suitable grout pressure for the particular hole. As the maximum allowable pressure is governed by foundation conditions, it is necessary for the inspector to determine an efficient rate of injection (number of sacks of cement per hour). This is done by varying the grout mix and the pressure without exceeding the maximum allowable pressure.

It has been found convenient to base grout mixtures on volumetric water-cement ratios. The consistency of the mix used depends on geologic conditions of the rock, and on the rate of injection. The range of water-cement ratios for grout mixtures may extend from 20:1 for thin grout to 0.5:1 for thick grout. As a general rule, the grout mixture used during the initial injection period for any hole should be thin, ranging from 10:1 to 5:1. By using a thin mix at the beginning of grouting operations, the inspector is able to observe the behavior of the grout hole and to minimize the chances of prematurely plugging the hole by using too thick a grout.

Accepted foundation grouting procedure specifies that the optimum rate of grout injection is that which permits the greatest quantity of cement to be forced into the foundation rock without causing appreciable displacement of the surface. With this in mind, the engineer should control the mix or pressure to achieve this purpose. When a thin grout mixture can be pumped readily without developing the maximum permissible pressures, the quantity of cement being injected can be increased by decreasing the water-cement ratio and maintaining the resulting higher pressures. Grout that is too thick may fill the rock fractures partly; however, grout that is too thin may shrink when it sets, unless the pressure is sufficient to force the excess water out of the mixture into the surrounding rock. The optimum grout mix, therefore, is one that contains the minimum volume of water necessary to carry the cement into all rock voids and fractures.

In order to determine the allowable pressure, the engineer must know the rock structure, depth of zone being grouted, and permissible magnitude of foundation movement, if any. In general, sedimentary rocks having horizontal bedding cannot be grouted with pressures as high as those used for grouting steeply dipping sedimentary or badly fractured igneous or metamorphic rocks. If it is necessary to place a rigid structure on a part of the foundation before it has been grouted, measurements of surface movement near the structure should be made while grouting is in progress.

The conditions to be met before grouting of any hole can be terminated are usually stated in the construction specifications. Present specifications of the USBR require:

> "* * * that the grouting of any hole shall be continued until the hole or grout connection takes grout at a rate of less than one cubic foot of the grout mixture in 20 minutes if pressures of 50 pounds per square inch or less are being used, in 15 minutes if pressures between 50 and 100 pounds per square inch are being used, in ten minutes of pressures between 100 and 200 pounds per square inch are being used, and in five minutes if pressures in excess of 200 pounds per square inch are being used."

Other specifications state that grouting shall be continued until "refusal." This means that grout is applied to the hole at maximum pressure until it sets within the hole or pipe nipple. Obviously, this condition applies only when the circulating grout system is used for supplying grout to the hole.

Asphalt-Grouting Methods

Large subsurface flows of water are difficult to stop by grouting with cement or clay grout. For this condition, asphalt grouting has been used successfully. This method of grouting has proved particularly effective in sealing watercourses in underground rock channels. In addition, it has been used to plug leaks in cofferdams and in foundation rock.

The principal items of equipment required for asphalt grouting are heating tank, pump, supply lines, and gages. A suitable arrangement of equipment is shown in Fig. 6. A commercial asphalt heater similar to those used by roofing contractors has been found satisfactory. The heater should be provided with a baffle near the outlet to prevent lumps of asphalt from entering the supply line. Gear pumps, reciprocating pumps with ball valves, or 1-in. boiler-feed piston pumps have been used to pump asphalt grout. The supply lines are fabricated from 1.5-in. standard black iron pipe. The grout pressure gage is connected to the supply line by a 1-in. nipple and "pigtail" siphon. In order to prevent asphalt grout from plugging the gages the 1-in. nipple is filled with grease and the siphon is filled with oil.

Often, when grouting during cold weather, it is necessary to provide a method for heating the supply lines. One successful method is to insert an insulated, heavy, iron wire within the supply line. One end of this wire is connected to the bottom of the supply line; and the other end, to a high-amperage, low-voltage generator, such as is used in commercial welding machines. The machine is grounded to the supply line at a point where the

supply line joins the pump. Steam has also been used to heat the supply line, but has proved cumbersome and costly.

Asphalt with a melting point between 165° F and 175° F has been found suitable for grouting. This material is heated to temperatures ranging from 400° F to 500° F before it enters the pump. The asphalt should be clean—that is, free from trash, gravel, or other debris. If the grout contains such materials, they will settle to the bottom of the heater and cause the formation of "hot spots" which result in premature deterioration of the heater. Coal-tar pitch is not a desirable material for grouting because it melts more slowly and chills more quickly than asphalt grout. Moreover, when pitch is heated above its melting point, it emits fumes which are dangerous to personnel.

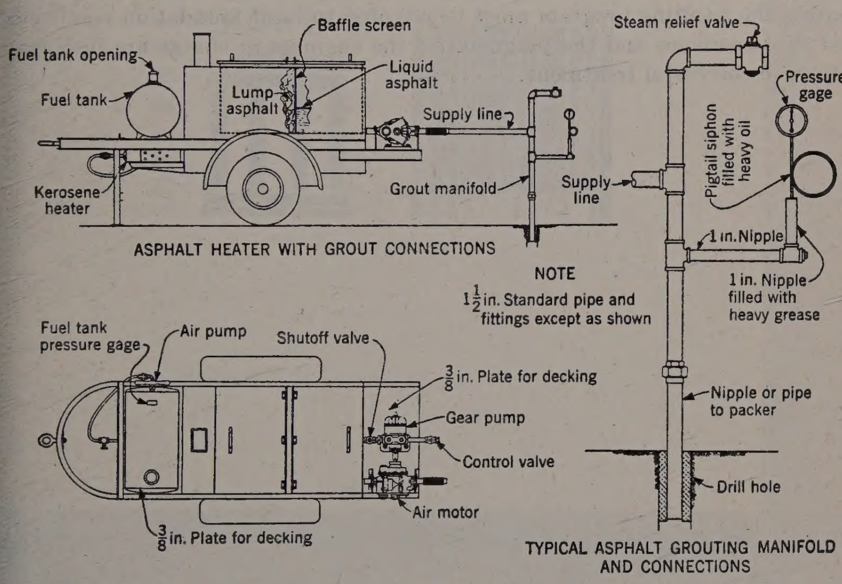

Fig. 6.—Asphalt-Grouting Equipment and Connections

Most grout holes contain some water; and, when hot asphalt is pumped into the hole, steam will form. Some of this steam is caught in the supply line and rises to the manifold. To prevent steam from blowing back into the heater, a relief valve connected to the top of the manifold is opened periodically during the initial injection of grout into each hole.

Extensive precautions should be taken to protect workmen engaged in asphalt grouting operations. Gloves, goggles, and ointment on exposed skin should be used by all grouting personnel. Occasionally, accidents happen in this type of grouting and precautions must be taken to prevent them.

Summary

This paper describes the present-day practices of the treatment of foundations of large dams by the USBR. Most of the future dams to be built on

rock foundations will require some form of foundation treatment. Experience has proved that, when properly executed, pressure grouting effectively serves its purpose of improving foundations. Positive displacement pumps and mechanical mixers guarantee a continuous injection, and packers add to the control of pressures, thereby increasing the efficiency of the operation. Neat cement is still the most effective grouting material where permanence and strength are prerequisites. Certain admixtures are sometimes used under special conditions; but, generally, they offer no advantage in foundation grouting. Hot asphalt has proved effective in stopping large flows of water that could not be controlled by cement grout. Chemicals will penetrate smaller openings than cement but as yet chemical grouting is in the development stage and has not been proved on a large scale. The basic procedure used in executing the grouting program must be adapted to local foundation conditions and the experience and the judgment of the engineer in charge are important factors in successful treatment.